

# DIFFERENCE BETWEEN EVEN AND ODD 11-YEAR CYCLES IN COSMIC RAY INTENSITY

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## ABSTRACT

Cosmic ray data for the period 1946-1984 are used to determine the run of the cosmic ray intensity over three complete solar cycles. The analysis shows a tendency towards a regular alternation of cosmic ray intensity cycles with double and single maxima. Whereas a saddle-like shape is characteristic of even cycles, odd cycles are characterized by a peak-like shape. The importance of this behaviour is discussed in terms of different processes influencing cosmic ray transport in the heliosphere.

1. Introduction. The anomalous behaviour of the cosmic ray intensity after the 1968 solar maximum in the 20th solar cycle has been described by several authors. This was characterized by the softening of the spectra (Evenson et al., 1983), the sudden recovery of the intensity (Kuzmin et al., 1977), a poor correlation of the cosmic ray intensity with solar activity (Akopian et al., (1981) and the sudden appearance of anomalous components in the cosmic rays (García Muñoz et al., 1981; McDonald et al., 1981).

The purpose of this study is to show that the 1946-1957 11-year cycle in cosmic ray intensity also presents this characteristic behaviour and that this seems to be the result of a similar behaviour in solar activity during even sunspot cycles. A possible physical interpretation to this phenomenon is given in terms of different contributions of drift, convection and diffusion to the whole modulation process.

2. Data. The basic data used in the present study are the monthly values of the cosmic ray intensity and the smoothed sunspot numbers over the period 1946-1984, thus covering three complete 11-yr cosmic ray intensity cycles. As the cosmic ray data are derived from the ion chamber at Huancayo (1946-1957) and the neutron monitor at Deep River (1958- 1984), and they represent two different kinds of data, we integrated them following the method described by Nagashima and Morishita (1980) which, from the point of view of long term modulation, is permissible as a first approximation.

In Figs. 1a. and 1b. the smoothed sunspot number and the integrated cosmic ray intensity over the period 1946-1984 are shown. The cosmic ray intensity is expressed in percent decrease with respect to the maximum intensity level

established in May, 1965. The cosmic ray intensity, on the other hand, was smoothed using an ultra lowpass filter which essentially gives the trend of the input function and effectively removes the rapid fluctuations (Behannon and Ness, 1966). The smoothed intensity is shown as the dashed curve in Fig. 1b.

In these curves the hatched regions represent the times of reserval of the solar magnetic field and the notation  $\vec{M} \uparrow \uparrow \vec{\Omega}$  and  $\vec{M} \uparrow \downarrow \vec{\Omega}$  indicates the magnetic moment parallel and anti-parallel to the angular velocity axis of rotation of the Sun, respectively.

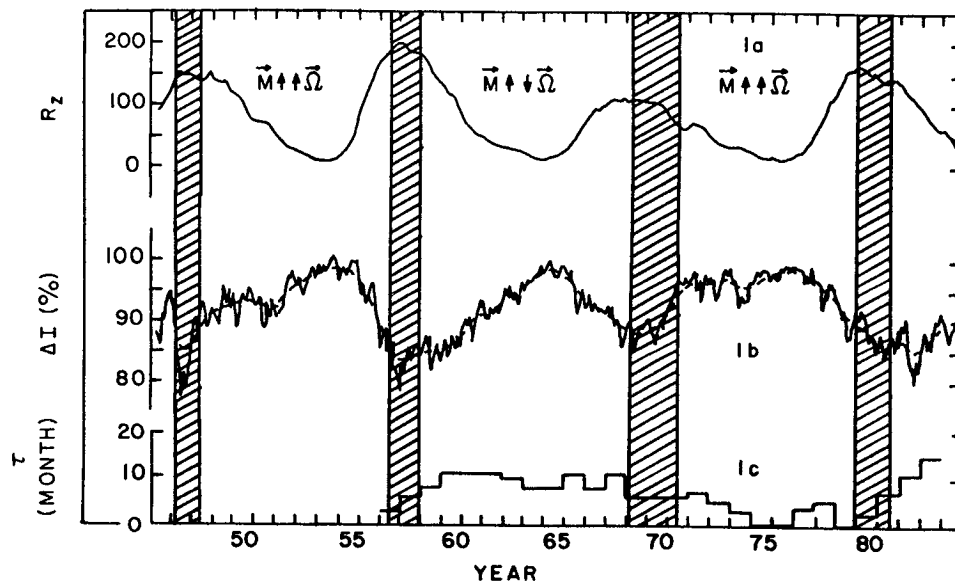


Fig. 1. a) Zurich sunspot number. b) Integrated cosmic ray intensity (solid line) and smoothed curve (dashed line). c) Time lag of intensity behind sunspot number for 11 years from  $t-10$  years to  $t$ .

3. Results and Discussion. From the smoothed curve of cosmic ray intensity shown in Fig. 1b, one can see that the shape of the  $\vec{M} \uparrow \uparrow \vec{\Omega}$  cycles differs systematically and markedly from the shape of the  $\vec{M} \uparrow \downarrow \vec{\Omega}$  cycle. Whereas the shape of the  $\vec{M} \uparrow \downarrow \vec{\Omega}$  cycle is characterized by a simple and relatively smooth increase to the maximum ( $\sim 7.5$  yr), the  $\vec{M} \uparrow \uparrow \vec{\Omega}$  cycles, on the average, are characterized by a two maxima structure in which the first maxima is reached relatively rapid after the previous minimum in the cosmic ray intensity ( $\sim 3-4$  yr) and the second, the main and also more developed, tends to occur

at the same time in the cycle that the maximum of the  $\vec{M}\uparrow\downarrow\vec{Q}$  cycle.

This different behaviour between  $\vec{M}\uparrow\uparrow\vec{Q}$  and  $\vec{M}\uparrow\downarrow\vec{Q}$  cycles is also shown in the time lag  $\tau$  of cosmic ray intensity behind solar activity, as measured by the smoothed sunspot number. This 22-yr variation in the time lag, already found by Nagashima and Morishita (1980), in which  $\tau$  is greater in  $\vec{M}\uparrow\downarrow\vec{Q}$  cycles than in  $\vec{M}\uparrow\uparrow\vec{Q}$  cycles, as can be seen in Fig. 1c, clearly shows that particles reach the Earth more easily when their access route is by the heliospheric polar regions than when they gain access along the current sheet (Kota and Jokipii, 1982). In this case as the route of access becomes longer due to the waviness of the neutral sheet the time lag  $\tau$  is also longer as one would expect from theoretical considerations.

However, what this model does not explain is the two maxima structure during the  $\vec{M}\uparrow\uparrow\vec{Q}$  cycles. This behaviour is, in fact, also present in solar (Dodson and Hedeman, 1975) and in geomagnetic activity as measured by the aa-index (Halenka, 1983). According to the Dodson and Hedeman's results the solar activity during even sunspot cycles are characterized by two well defined "stillstands" in the level of activity during the declining phases of such cycles. On the other hand, Halenka shows that the aa-index during even solar cycles also presents this characteristic while the odd cycles do not.

Therefore, the results shown here clearly establish a marked distinction between even and odd solar activity cycles which in turn are reflected both in geomagnetic activity and cosmic ray intensity.

4. Conclusions. The results presented above point out towards a modulation mechanism, during even cycles, where convection plays a more important role than during odd cycles, where diffusion dominates, while the effect of drifts only determines how the particles gain access to the observation point. That is, charge dependent effects are not the dominant processes in cosmic ray modulation.

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